DOT/FAA/AM-00/31

Office of Aviation Medicine
Washington, D.C. 20591

Impact of Aviation Highway-in-the-Sky Displays on Pilot Situation Awareness

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October 2000

Final Report

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20001129 044

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/AM-00/31		

4. Title and Subtitle	5. Report Date
Impact of Aviation Highway-in-the-Sky Displays on Pilot Situation Awareness	October 2000
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Williams, K.W.	
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
FAA Civil Aeromedical Institute P.O. Box 25082 Oklahoma City, OK 73125	11. Contract or Grant No.
12. Sponsoring Agency name and Address	13. Type of Report and Period Covered
Office of Aviation Medicine Federal Aviation Administration 800 Independence Ave, S.W. Washington, DC 20591	14. Sponsoring Agency Code

15. Supplemental Notes

This work was performed under task AM-A-00-HRR-519.

16. Abstract

Thirty-six pilots were tested in a flight simulator on their ability to intercept a pathway depicted on a highway-in-the-sky (HITS) display. While intercepting and flying the pathway, pilots were required to watch for traffic outside the cockpit. Additionally, pilots were tested on their awareness of speed, altitude, and heading during the flight. Results indicated strong practice effects for a pilot's ability to intercept the pathway and that the presence of a flight guidance cue significantly improved performance. The ability to spot traffic was more affected by task difficulty than by display appeal. New display concepts are needed for supporting secondary flight information present on the HITS display. Recommendations for training and use of HITS displays are given, along with recommendations for display enhancements to support situation awareness.

17. Key Words	18. Distribution Statement
Situation Awareness, Pathway Displays, Highway-in-the-Sky Displays, Cockpit Displays, Perspective Displays, Applied Psychology	Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	13	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGMENTS

The author thanks Dr. Tom Nesthus and Jared Fasion for collecting the eye-gaze data, Howard Harris for recruiting and scheduling participants, Barry Runnels for maintaining the Advanced General Aviation Research Simulator, and Tom Philps and Deborah Thompson for their assistance in reducing the eye-gaze data.

Impact of Aviation Highway-in-the-Sky Displays On Pilot Situation Awareness

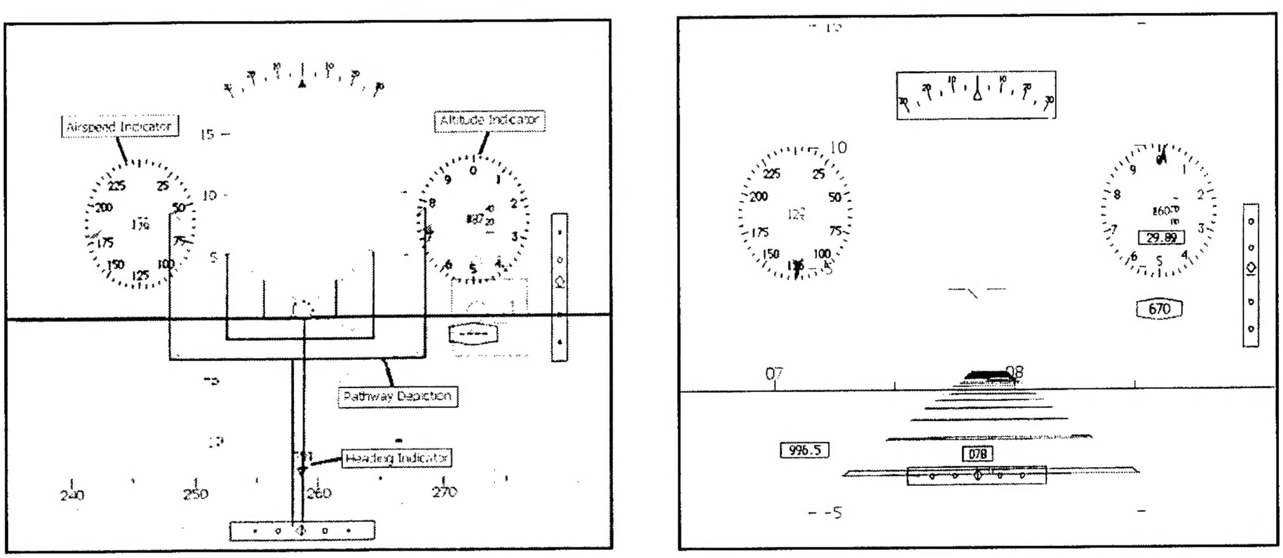
INTRODUCTION

Recently, a great deal of attention has been given to the incorporation of a Highway-In-the-Sky (HITS) display as the primary cockpit flight display. A HITS (also called "pathway") display provides course guidance to the pilot using a perspective view of a path through the air. Figures 1a and 1b provide examples of typical HITS displays. Interest in this type of display is not new, originating in the 1950s with the Joint Army-Navy Instrumentation Program (see Warner, 1979). Until recently, however, the implementation of a HITS display was too expensive for most aircraft owners.

Two technological breakthroughs have made it feasible for HITS systems to become a reality in most aircraft cockpits. One of these is an affordable Global Positioning System (GPS) receiver that provides real-time, accurate aircraft position information. The second breakthrough is the production of inexpensive, yet powerful, graphic display systems that are capable of providing real-time HITS depictions in the cockpit. Both of these technologies make HITS displays feasible for general aviation (GA) aircraft. Given the availability of more affordable HITS displays, the Advanced General Aviation Transport Experiments (AGATE) consortium, which is dedicated to the specification of a next-generation GA aircraft, has mandated the incorporation of the display as its top priority in judging the success of its program.

Although HITS displays have the potential to replace many of the older display formats that have been the mainstay of GA aircraft, the exact purpose and use of a HITS display is still being debated. Research is required to answer critical questions regarding the effectiveness and safety of these displays. One of these questions is how well a pilot maintains situation awareness (SA) while flying with a HITS display.

Problems with SA have been implicated as a leading causal factor in both military aviation mishaps (Endsley, 1997) and accidents among major air carriers (Endsley, 1995). The current study was designed to look at the effect that a HITS display would have on pilot SA. In particular, three types of SA were considered in the study.



a. **b.**

Figure1. a) Goal post pathway design showing pathway, airspeed, altitude, and heading indications. b) Paving stone pathway design.

The first type of SA involved knowledge of the position of the intended flight path, relative to the current position of the aircraft. The HITS display depicts a volume of space in the real world and the position of the aircraft in relation to this volume of space. Endsley (1997) refers to this type of SA as Spatial/Temporal SA. Wickens (1995) suggests that one of the major deficiencies of three-dimensional (D) perspective displays, of which the HITS display is one example, is the "ambiguity of position estimate along the line of sight or viewing vector of the display" (p. K2-9). When approaching the pathway from the outside, there are very few visual cues to indicate distance from the pathway. In this situation, some cues, such as binocular disparity and textural gradients, are unavailable. Other cues, such as relative size, can be distorted. The ability of the pilot to maintain awareness of the position of the aircraft relative to the pathway is important. The present study was designed to provide information on the effects that different pathway formats and guidance cues have on the ability of pilots to establish their aircraft on the pathway.

A second type of SA addressed here is the ability to locate other aircraft. Referred to as tactical SA (Endsley, 1997), the need to maintain awareness outside of the cockpit is critical to flight safety. The impact of new flight displays and controls on the amount of time spent looking outside of the cockpit has been studied primarily within the context of an airline cockpit (e.g., Damos, John, & Lyall, 1999; Rudisill, 1994; Wiener, 1993). In those studies, the complexity of interacting with the display was shown to be the main driver of how long and how often the pilot focused attention outside of the cockpit. For HITS displays, previous observations of pilots using a head-down HITS display had suggested that significant proportions of flight time were spent viewing the HITS to the exclusion of other piloting activities. Therefore, the ability of the pilot to maintain awareness outside of the cockpit was examined in the current study by having the pilot scan for aircraft traffic while acquiring and flying the pathway.

A final type of SA addressed in the current study is knowledge of secondary information available on the HITS display. Information about the current airspeed, aircraft heading, and altitude is present in the display, but there is a question of whether such information is necessary and what circumstances would make the information necessary. Researchers have examined pilot information requirements (Schwaneveldt, Lamonica, Tucker, Nance, & Beringer, 2000), but that research did not consider the effect that a HITS display would have on those requirements. Of interest in the current study is how aware pilots are of the secondary information available on the HITS display and whether they use that information during flight.

METHODS

Participants

Thirty-six pilots, holding at least a current private pilot certificate, were recruited locally. Information was collected regarding each participant's education level, gender, flight experience, and age. Flight experience averaged 830 hours. Twenty-one of the 36 pilots (58%) held an instrument rating. The average age of the pilots was 37, ranging from 19 to 67 years. Median pilot age was 30.5 years.

Facilities and Equipment

Data collection was performed using the Advanced General Aviation Research Simulator (AGARS) located at the FAA Civil Aeromedical Institute in Oklahoma City. The AGARS is a high-fidelity, fixed-base flight simulator. The controls and displays used in this study simulated those of a Piper Malibu, which is a single-engine, high-performance aircraft with a retractable landing gear. Control inputs are provided by high-fidelity, analog controls, including rudder pedals, throttle, gear, flap, and trim controls. The HITS display appeared on a cathode ray tube (CRT) located on the right side of the cockpit. Pilots flew the simulation from the right seat during the study.

In addition, a video eye-tracking system was used to record pilot gaze position during each flight. The EL-MAR, VISION 2000 system, from EL-MAR Incorporated, was used for this experiment. In this head-mounted system, a miniature scene camera captures the subject's field of view. Imagery from the scene camera is electronically combined with a moveable cursor corresponding to the horizontal and vertical position of the eye. The combined imagery is recorded on videotape, showing the relationships between the subject's gaze and objects in the field of view.

Experimental Design

Two factors relating to pathway acquisition were manipulated in the experiment: 1) Pathway type (goal posts or paving stones); and 2) guidance symbology (follow-me airplane, flight predictor only, or none), resulting in a 2 x 3 repeated measures design. Figures 1a and 1b show how both of the pathway types appeared when viewed from the center of the path. Figure 2 shows the guidance symbology, including the follow-me airplane symbol, flight predictor velocity vector, and pitch reference symbol. Display functioning was not quickened or unburdened in any fashion (Frost, 1972). Pathway type was counterbalanced across participants, while guidance symbology was counterbalanced within pathway type.

Procedure

Participants were tested individually. Each pilot received a consent form to read and sign and then completed an experience questionnaire. Following completion of the questionnaire the participants were shown the HITS display and given an overview of the flight task. A calibration procedure for the eye-tracking equipment was then performed, but pilots were not required to wear the eye-tracker until after a practice flight in the simulator. They were then placed in the simulator and familiarized with the location of the controls and displays needed during the flight.

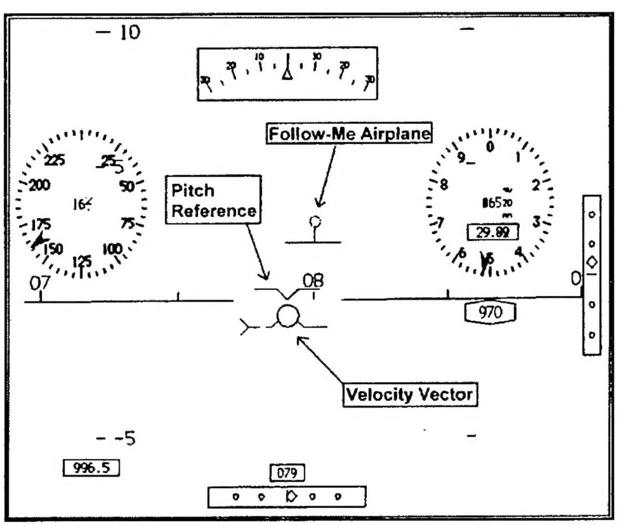


Figure 2. Display guidance symbology used in the experiment. Note that under the 'no-guidance' condition, only the pitch reference symbol was visible (from Beringer, 1999, reprinted with permission of author).

After the pilot was familiar with the aircraft displays and controls, a ten-minute practice flight was conducted. The pilot was then fitted with the EL-MAR eye-tracking equipment, and the experimental trials were begun. Pilots completed three flights, were given an opportunity for a break, and then completed the remaining three flights. Following completion of the experimental task, participants were asked about their display preferences. Their preferences were recorded, participants were debriefed, and they were then dismissed.

All pilots flew six scenarios, lasting between 9 and 12 minutes each. The highway-in-the-sky path was positioned as a traffic pattern around Runway 08 of Albuquerque International Airport; however, pilots did not fly the entire pattern during the scenarios. Instead, after take-off, pilots were instructed to climb to 100 feet (30.5 m) above ground level while holding the runway heading and then begin a left turn to a heading of 310 degrees. Pilots intercepted the downwind portion of the pathway generally between 7500 and 8000 feet mean sea level. The pathway was then followed until midway through the base leg for scenarios one through five and until turning to final for scenario six. Each scenario was ended with the aircraft in midair by blanking out the screens and resetting the aircraft to the runway. At the end of the third and sixth scenarios, after the displays had been blanked out, pilots were asked to estimate their airspeed, heading, and altitude. The actual and reported airspeeds, headings, and altitudes were recorded.

During three of the six scenarios, selected randomly, two aircraft flew within the field of view and were visible on the out-the-window screens for 20 seconds to 1 minute. Pilots were instructed to indicate when these aircraft were detected by making a traffic call over the radio, using a push-to-talk switch located on the yoke. Traffic scanning task complexity was manipulated by controlling the timing of when each aircraft appeared in the pilot's field of view. One aircraft appeared in the field of view as the pilot was in the process of establishing on the pathway and for a short time thereafter (high complexity condition). The other aircraft appeared during a straight portion of the path when very little input was required to maintain position on the path (low complexity condition). These targets were referred to as off-path and on-path targets, respectively.

RESULTS

Intercepting the Pathway

To analyze the ability of pilots to intercept the pathway, horizontal and vertical deviations from the pathway were recorded at 1-second intervals. Recording began when the aircraft first approached within 100 feet (30.5 m) horizontally of the path and continued for the next 60 seconds. Only one pilot, during one of the six experimental trials, failed to approach to within 100 feet (30.5 m) of the path. The data from this pilot were not included in the analyses. This particular pilot was the oldest pilot participating in the experiment (67 years old).

Horizontal Deviation Analyses. A 2 x 3 (pathway type by guidance condition) repeated measures analysis of variance was conducted on the horizontal root mean square errors (RMSE). The only difference to reach significance was the main effect for guidance condition, $F(2, 68) = 6.875$, $p < .01$. The means for the horizontal RMSE for the no-guidance, flight predictor, and follow-me airplane conditions were 560 feet (170. m), 293 feet (89.4 m), and 108 feet (32.9 m), respectively. Figure 3 shows the horizontal errors separated by guidance and pathway conditions. Post-hoc analyses demonstrated a significant difference between the no-guidance and follow-me airplane conditions, $t(34) = 3.002$, $p = .005$, and between the flight predictor and follow-me airplane conditions, $t(34) = 2.845$, $p = .007$, but not between the no-guidance and flight predictor conditions $t(34) = 1.982$, $p = .056$. Clearly, pilots had less horizontal error while acquiring the pathway when they were using the follow-me airplane.

Vertical Deviation Analyses. A 2 x 3 (pathway type by guidance condition) repeated measures analysis of variance was conducted on the vertical RMSE. As with the horizontal errors, a significant effect for guidance condition was found, $F(2, 68) = 11.365$. $p < .001$. Mean RMSE values for the no-guidance, flight predictor, and follow-me airplane conditions were 162 feet (49.4 m), 128 feet (39 m), and 52 feet (15.9 m) respectively. Again, as with the horizontal errors, post-hoc analyses indicated a significant difference between the flight predictor and follow-me airplane conditions, $t(34) = 4.829$, $p < .001$, and between the flight predictor and no-guidance conditions, $t(34) = 3.928$, $p < .001$, but not between the no-guidance and flight predictor conditions, $t(34) = 1.605$, $p = .117$. Pilots committed significantly less error vertically when using the follow-me airplane than when acquiring the pathway without it.

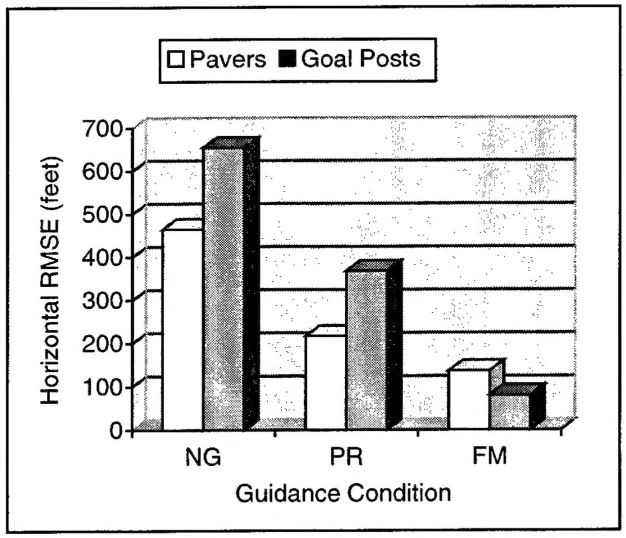


Figure 3. Horizontal RMSE for each guidance and pathway condition – NG = no-guidance, PR = flight predictor only, and FM = follow-me airplane.

In addition to the significant main effect for the guidance condition, there was also a significant interaction between guidance condition and pathway type, $F(2, 68) = 4.457$, $p = .015$. Post-hoc analyses indicated that vertical error was significantly greater during pathway acquisition with the paving stone display than with the goal post display (171 feet vs. 84 feet [52.2 m vs. 25.6 m]) when only the flight predictor was used, $t(34) = 3.601$, $p = .001$. Figure 4 shows a graph of this interaction.

Practice Effects. To look at the effect of practice on the pilot's ability to acquire the pathway, a separate analysis of vertical and horizontal error across trials was conducted. For these analyses, only trial number (1 to 6) was treated as an independent variable. A repeated measures analysis of variance found a significant effect for trial number for both the horizontal error, $F(1, 35) = 5.576$, $p < .001$, and the vertical error, $F(1, 35) = 3.89$, $p = .002$. Figure 5 shows both of these types of error across trials. That pilots continued to improve across trials is clear from the figure.

Subjective Comments

After completing all of the experimental trials, pilots were asked which of the pathway types was easier to acquire and whether the guidance provided made it easier to acquire the pathway. Twenty-eight of the 36 pilots (78%) believed that the goal post display was easier to acquire than the paving stone display. Only five (14%) believed that the paving stones were easier to acquire and three (8%) thought there was no difference between the two pathway types.

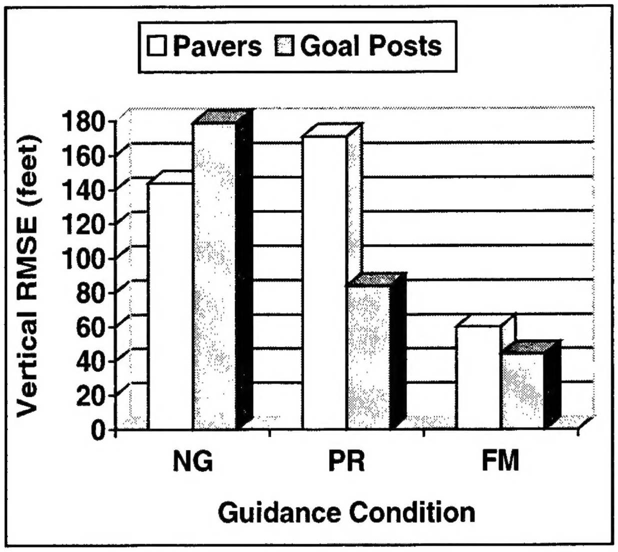


Figure 4. Vertical RMSE for each guidance and pathway condition – NG = no-guidance, PR = flight predictor only, and FM = follow-me airplane.

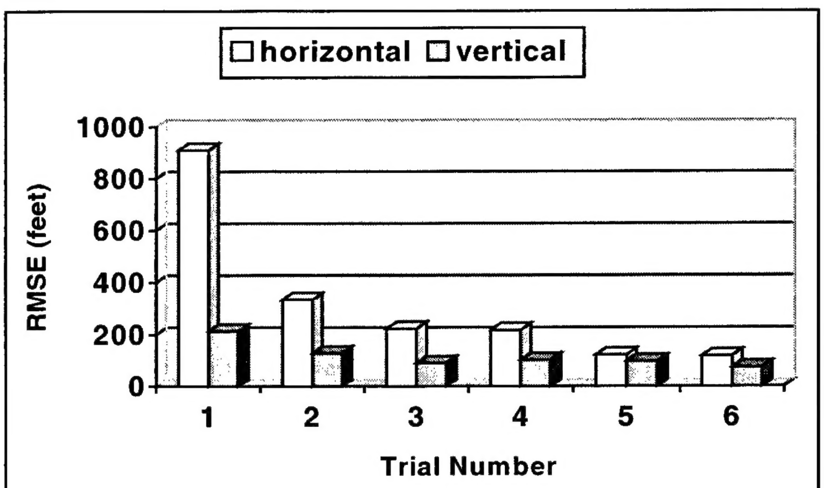


Figure 5. Vertical and horizontal error during pathway acquisition by trial number.

Regarding the effect of flight guidance on pathway acquisition, 26 of the pilots (72%) thought that the follow-me airplane symbology made it easier to acquire the pathway. Five pilots (14%) believed that the use of the flight predictor without the follow-me airplane was more effective for acquiring the pathway, and 5 pilots (14%) did not think that any of the guidance symbology was useful for acquiring the pathway. It is interesting to note the large percentage of pilots who expressed a preference for the goal post over the paving stone pathways, even though few actual performance differences were obtained.

Spotting Traffic

Overall, pilots spotted an average of 3.25 aircraft out of the six, although some pilots were able to spot all six aircraft while others spotted none. A one-sample t-test demonstrated that pilots located significantly fewer aircraft than were possible, $t(35) = -7.427$, $p < .001$. In addition to this finding, a separate analysis was conducted comparing the number of off-path and on-path targets that were located. On average, pilots located 1.33 off-path targets (high-complexity condition) and 1.92 on-path targets (low-complexity condition). A paired t-test showed that this difference was significant, $t(35) = 2.78$, $p = .009$.

Two things are clear from the current data. 1) Pilots are able to spot traffic while using the HITS display. Although only about half of the traffic was spotted overall, pilots clearly differed in their ability to spot traffic, even though their experience with the display was equivalent. Other factors besides the novelty of the display had to play a role in these differences. 2) Task complexity was a major contributor to the pilot's ability to spot traffic because significantly more traffic was spotted under the low-complexity condition than under the high-complexity condition.

Eye-Gaze Data

To analyze the eye-gaze data, the percentage of time during each flight that was spent looking out of the cockpit was computed. The eye-gaze videotapes were reviewed, and a count was made of both the number of times that the pilot looked out the cockpit and the total time that was spent looking

out of the cockpit. The total time count was then divided by the length of the flight to get a percentage of the time during the flight in which the pilot was looking out of the cockpit. The time that pilots spent looking out of the cockpit across all flights varied from 0% to 52%, with a mean of 14% and a median of 10%. A 2 x 3 (pathway type by guidance condition) repeated measures analysis of variance was performed on the percentage scores to see if there were any differences in head-out time due to differences in pathway type or usage of guidance symbology. No significant effects were found.

In addition, correlations were computed between head-out time and several performance and demographic variables. Table 1 presents the correlations between these variables. As expected, head-out time was significantly correlated with the number of aircraft spotted. Head-out time was also significantly negatively correlated with age, indicating that older pilots spent less time head-out than did younger pilots. Head-out time was not significantly correlated with either total flight time or flight time during the last 90 days.

Awareness of Secondary Display Information

Pilot estimates of airspeed, heading, and altitude were recorded along with actual corresponding system values following completion of the third and sixth trials. Responses were scored as "hit" or "miss" if they were within a specified range of the actual values. The range for each aircraft parameter was selected based on practical test standard values for private pilots. Each range was twice that specified in the practical test standards for performance of most private pilot maneuvers – ± 20 knots for airspeed, ± 20 degrees for heading, and ± 200 feet (61 m) for altitude. Estimates were scored as a miss if they fell outside the ranges specified or if the pilot said "don't know," "no idea," etc. for the estimate.

Of the 72 total estimates given for each value (36 subjects x 2 estimates per subject = 72 total estimates), pilots were correct 59 times for airspeed (82%), 32 times for heading (44%), and 22 times for altitude (31%). The number of correct estimates differed significantly across the three information types, $\chi2(2, N = 72) = 40.79$, $p < .001$.

A comparison was performed of the difference between the first time that pilots were asked to make estimates and the second time they made estimates. For the airspeed estimates, 28 (78%) gave correct estimates the first time and 31 (86%) estimated correctly the second time; not a significant improvement. For the heading estimates, nine (25%) correctly estimated the first time, while 23 (64%) estimated correctly the second time. A paired t-test showed a significant difference in correct estimates, $t(35) = 4.95$, $p < .001$. Only four (11%) correctly estimated their altitude the first time they were asked. This improved to 18 correct estimates (50%) for the second attempt. This improvement was also found to be statistically significant, $t(35) = 3.86$, $p < .001$. The most dramatic errors were committed when estimat-

Table 1.
Intercorrelations Between Percentage of Head-Out Time, Performance, and Demographic Variables.

Variable	1	2	3	4	5	6	7
1. Head-out time (%)	--	.496[b]	-.315	-.176	-.502[b]	-.247	-0.58
2. Number of aircraft spotted		--	-.117	-.217	-.329[a]	-.169	.117
3. Mean horizontal error			--	.751[b]	.692[b]	.416[a]	-.226
4. Mean vertical error				--	.509[b]	.114	-.304
5. Age					--	.500[b]	-.390[a]
6. Total flight time						--	-.196
7. Flight time – last 90 days							--

[a] Correlation is significant at the .05 level (2-tailed, $n = 36$).
[b] Correlation is significant at the .01 level (2-tailed, $n = 36$).

ing altitude. Ten pilots were off by > 1000 feet (305 m) the first time they estimated their altitude; one pilot was > 4000 feet (1220 m) in error.

DISCUSSION

This study examined the effect of pathway symbology and guidance cues on pathway acquisition, and the ability of the pilot to establish the airplane on the path in such conditions. Awareness of the position of the airplane relative to the intended flight path is one of the primary functions of a HITS display; however, little research has been conducted regarding maintaining that awareness under various unexpected conditions. Reising and Barthelemy (1991), for example, examined the effect of a HITS display on the pilot's ability to recover from unusual attitudes. However, in that study, pilots began each trial on the pathway (though at an unusual attitude relative to the floor of the pathway). It seems likely that a pilot using a HITS display will, at some point, become distanced from the pathway, whether by design through evasive maneuvers, or unintentionally, and will need to reposition the airplane back on the path. Consequently, the need for this type of study becomes obvious.

When comparing the two pathway types for ease of acquisition, little difference was found between the goal-post display and the paving-stone display. There was some indication that vertical error was less using the goal-post display, but that advantage was nullified when a follow-me airplane aided the pilot in intercepting the pathway. Therefore, for pathway interception and acquisition, the manner in which the pathway was depicted had little overall effect. In contrast, 78% of the pilots felt that it was easier to intercept and acquire the pathway using the goal-post display than when using the paving-stone display. This finding is reminiscent of the review by Andre and Wickens (1995) demonstrating that the favorableness of a display is not necessarily a good indication of its effectiveness.

A second finding was that use of the follow-me airplane significantly enhanced the ability of a pilot to intercept the pathway relative to using a flight predictor symbol alone or no-guidance symbology; however, the assistance provided by the follow-me airplane was most useful to pilots with little or no experience with a particular pathway type. Notably, the effect of practice at intercepting the pathway appeared to overwhelm any effects caused by differences in either the pathway or guidance symbologies, suggesting that the selection of pathway depiction, and the presence and functioning of guidance symbologies, are not as important as ensuring that pilots receive practice with the display. There still remains a question regarding how long the training remains effective. Further research is required to determine how often training would be required to maintain proficiency with the display.

One interesting result in the current study was the apparent tendency for some of the pilots, when first viewing the HITS display, to be unable to interpret the two-dimensional display as a representation of a three-dimensional volume of space. Pilots "flying through" the pathway, from one side to the other, without even attempting to turn the plane onto the pathway, manifested this tendency, which seemed to be more prevalent among the older pilots in the study. The inability of these pilots to extract three-dimensional information from a two-dimensional display is reminiscent of the work of Hudson (1960) on the inability of certain cultural groups to perceive specific types of two-dimensional drawings in three dimensions. Hudson concluded that differences in the tendency to make use of certain kinds of depth cues were the result of culturally mediated experiences. Perhaps the same type of finding was manifested in the current study. Although computer gaming experience was not assessed, it seems likely that the older pilots would have less computer gaming experience than would the younger pilots. In general, the older pilots seemed to experience more difficulty with the displays.

As mentioned earlier, the only pilot who failed to come within 100 feet of the pathway during one of the flights was the oldest pilot in the group. A significant positive correlation was found between age and the amount of horizontal and vertical error made during pathway acquisition. A significant negative correlation was found between age and the number of traffic targets located. There was also a significant negative correlation between age and the amount of time spent looking outside of the cockpit. Older pilots, in general, spent more time looking at the HITS display. Inexperience with these types of perspective displays could explain some of the pilots' difficulties in correctly interpreting three-dimensional volume from a two-dimensional depiction. Because not all depth cues are available in these displays, and

because some depth cues are distorted, an inexperienced viewer of the display could have difficulty interpreting the display. Again, practice with the display is an important aspect to successful display interaction.

The second type of SA examined in the present study was awareness of other airplane traffic. Even though pilots did not spot a significant proportion of the traffic, it is premature to conclude that the HITS display prevented or interfered with the ability to spot traffic relative to more traditional flight displays. A direct comparison of traditional and HITS displays was not performed. One question of interest for the current study was whether the HITS display would absorb attention that would otherwise be used to search for traffic simply because of the novel nature of the display. On average, pilots in the current study looked outside of the cockpit 14% of the time. No research could be found regarding how much time pilots in a GA environment normally spend looking outside, so it is difficult to make judgments; however, this percentage does seem low, especially for a flight occurring under visual flight rules (VFR).

Even though pilots in the current study looked outside of the cockpit 14% of the time on average, many demonstrated a willingness to take their attention away from the HITS display to search for traffic, as evidenced by the finding that some of the pilots were able to spot all of the traffic. Task complexity was shown to be a factor in their ability to locate traffic. There was a significant difference in the number of aircraft located during the high-complexity and low-complexity portions of the flight. As with studies of advanced avionics in airline cockpits (Damos, John, & Lyall, 1999; Rudisill, 1994; Wiener, 1993), the complexity of interacting with the display, and not display novelty, is believed to be the main driver of how long and how often the pilot focused attention outside of the cockpit.

The final type of SA that was studied was an awareness of flight parameters (airspeed, heading, and altitude) present on the HITS display. Pilots were much more successful at estimating airspeed than they were heading or altitude. One simple explanation for this result is that airspeed was less variable than either heading or altitude. Pilots could monitor this value less often but still have an accurate idea of their airspeed. It is interesting that the pilots had such difficulty with heading information (44% correct responses overall), given that the pathway headings were known to the pilot prior to the start of the experiment. If the pilot had been aware of which leg of the traffic pattern was being flown, it would have been possible to deduce the aircraft heading from the original runway heading. Some of the pilots, in fact, made this deduction; however, the majority did not.

One problem with querying the pilot's awareness of detailed aspects of a situation is that these details are not of concern to the pilot under all conditions (McGuiness, 1995). Most often, the pilot translates these data into a meaningful, qualitative state (e.g., too high, too slow, on course). However, it can be argued that, if the information presented requires translation before it becomes meaningful, it violates the principle of display design which states that the operator should not be required to derive functional properties of the system but should receive those properties directly (Lintern, Waite, & Talleur, 1999). Even if unaware of the exact values of certain flight parameters, the pilot should at least be aware of the trend of those values (slowing down, climbing, etc.). In addition to being least successful at guessing altitude information (31% overall, with only 11% correct estimates the first time they were queried), pilots were unaware that the airplane was slowly climbing from the point at which the pathway was first intercepted. The large majority of the estimates for the altitude were less than the altitude at which the airplane first intercepted the pathway, the altitude the pilots had been told to attain and hold until intercepting the pathway.

Several conclusions can be drawn from the results of this research. First, at least for the pathways tested in the current study, pathway depiction is not as important as practice with the display. Use of any particular HITS display should be predicated on the receipt of training for that display. The current study suggests that this training does not have to be extensive to be effective, but it should include situations that will expose the pilot to unusual interactions with the pathway. This will enable the pilot to become adept at interpreting the two-dimensional depiction as a three-dimensional volume of space. Second, task complexity has a more powerful effect on the ability to focus attention outside of the cockpit than does display novelty. Pilots can focus their attention on other aspects of flying as long as they do not find it too difficult to maintain the airplane on course and on the path. One possible solution to this problem is to place the HITS display on a head-up display

(HUD), thus allowing the pilot simultaneously to maintain both visual contact with the display and at least partial focus outside of the cockpit. Current research at the Civil Aeromedical Institute is looking at this issue. Finally, new display depictions are needed that will allow the pilot to easily track trends in flight parameters. It will not always be the case that the pathway will be straight and level. A general awareness of altitude, heading, and airspeed is important to the safety of the flight, especially if the HITS display should fail.

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